Interactive Design Exploration in Early Design Phase

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Abstract

The current research project seeks for design exploration strategies that can accommodate the flexible and ambiguous nature of creative exploration in early design phases, while providing the designer an access to a wide range of novel solutions. As computational analysis becomes faster for visualizing performance objectives, these are beginning to move to the early stage of design process. (Harding,2014) This change allows more information rich decision-making processes in the early design phase. However, it also brings a certain obsession with numbers and quantity, where qualitative aspects can easily get mixed with the quantitative performance. Therefore, this research followed an interactive strategy where the tacit knowledge of the designer is actively influencing the design search and exploration process.

During industry collaboration with the engineering office str.ucture GmbH, multiple criteria search strategies were explored within the framework of a textile façade system. Limitations of existing approaches such as constraint-based solvers and genetic algorithms were observed regarding their applicability in this stage. Accordingly, new tools were developed that can establish a better dialogue between human and computer, through integration of machine learning techniques and information rich search environments.

The project outline is a triangulated textile facade, installed on the existing steel structure of a car park. The triangulated steel structure was to be designed in consideration of the freedom and geometric limitations of a form fit steel connection which was developed as a digital detail by str.ucture and Design to Production. The joining system consists of form fit cog connections on a circular laser cut steel plate (Fig.1. Fig.2.) The façade design was strongly dependent on the systems geometric boundary conditions. Therefore, it was essential to develop a design workflow that can accommodate for the freedom in early design exploration while still aiming to optimize the geometry towards fabrication from this early stage on. To accelerate the process and providing aground for the discovery of novel solutions, the design exploration was automatized by using heuristics.(Harding,2014) While heuristic search could evaluate the design performance numerically the designer can access a large set of solutions and select the desired solution. Using such strategies, it was aimed to establish a negotiation between the numeric performance and aesthetic appeal where designers can define their own qualitative aspects considering both.

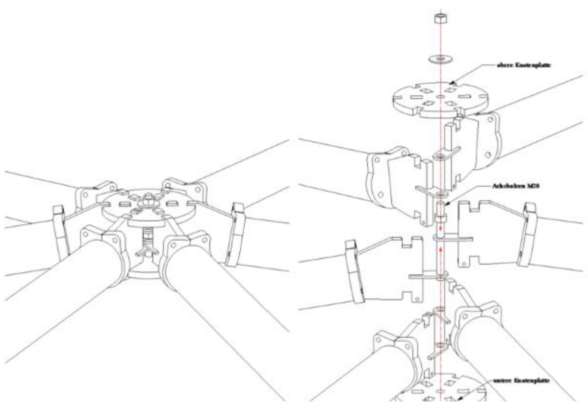


Figure 2 str.ucture- Axonometric detail of the circular laser cut plate, where the cogs are adjoined by simply plugging.

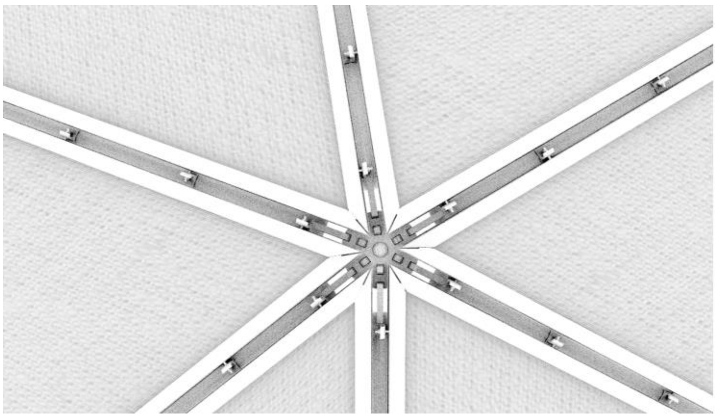
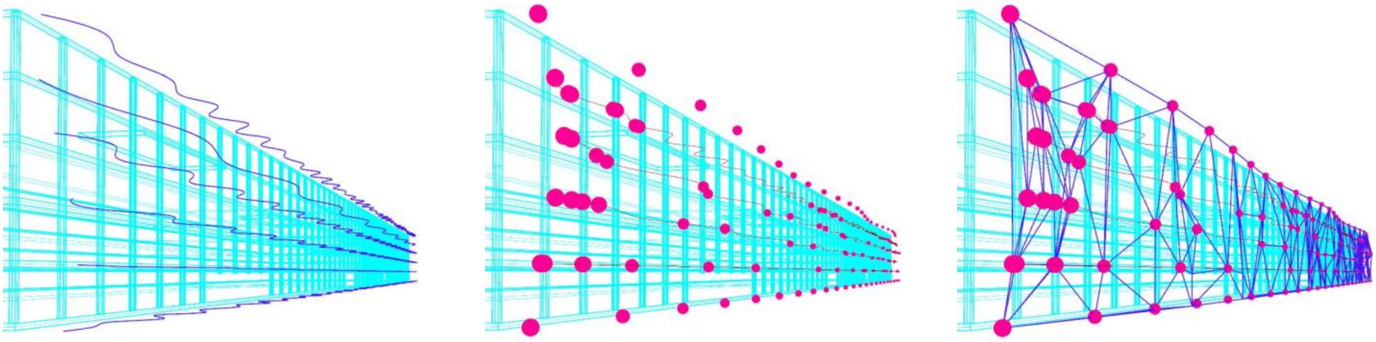


Figure 1: str.ucture-Rendering of the Joint detail after the attachment of the membranes.

To prepare a design problem for heuristics it must be turned into a mathematical equation defined by parameters, that control the design permutations and objectives that evaluate the solutions by a certain performance analysis. In this process, one of the most important aspects are the decisions taken in the parametrization of the problem, since a large set of parameters drastically increase the solution space, which ends up in long computation times to find good solutions.

In this case the problem was divided into two sections. A set of parameters were controlling the global geometry of the façade by using variable sine curves, generating a doubly curved surface. Another set of parameters were controlling the number of pieces and location of the joints on the surface given the limits of the existing construction. Taking these joints as vertices, the geometry was then planarized using a Delaunay triangulation method. (Fig.3 A,B,C) Using springs, elements with objective lengths restraints in Kangaroo (Piker,2013) , an ideal location for the joints were defined, regarding the fabrication constraints.



A *B* *C*

Figure 3 A,B,C Zeynep Aksöz - Steps of parametrization A raineling curves controlling the facade dept B joint distribution C triangulation

The objectives were defined regarding the fabrication constraints of the system, the structural stiffness and cost effectivity. Through the flexibility of the laser cutting process, the façade system can accommodate differentiated triangles. A minimum angle in between the elements to avoid collisions still had to be considered. Another limitation was defined by the membrane fabricator regarding the length of the edges, which should not exceed the maximum cut edge of the fabric roll. The existing structure of the car park was used as a framework to attach the façade. Therefore, some joints had to be installed on the existing construction and the façade depth should not exceed 1,5 m. (Fig.4)

In the first tests, Genetic Algorithm (GA) based multiple criteria search solver Octopus (Vierlinger,2013) was implemented into the workflow to navigate through solution spaces. Using such a fusion, different global geometries could be iteratively generated by GA and the constraints could be controlled by Kangaroo, while the solutions could be evaluated by GA according the amount of failures in the system regarding fabrication constraints and the structural and cost related goals. In this setup it was observed that many solutions in pareto optima were nearly ideal however at some locations completely incorrect. Even though these were labeled as good solutions by GA, it was impossible to fabricate these and therefore had to be labeled as invalid. As a result, instead of accelerating the design exploration process, this workflow was decelerating it by time consuming multiple criteria search and invalid solutions.

In a second iteration the parametrization was limited to avoid the mistakes in the solution set. In this case by default the joints were located on the existing structure and each joint was given limits of a bounding box to displace. The genetic algorithm was varying the location of each joint within the bounding box. In this method the number of elements were predefined, and the joint displacement was occurring within the limits of an optimized solutions. An important parameter of optimization was the limitation of stresses from temperature deformations by avoiding straight paths of linked elements within the triangulated system.

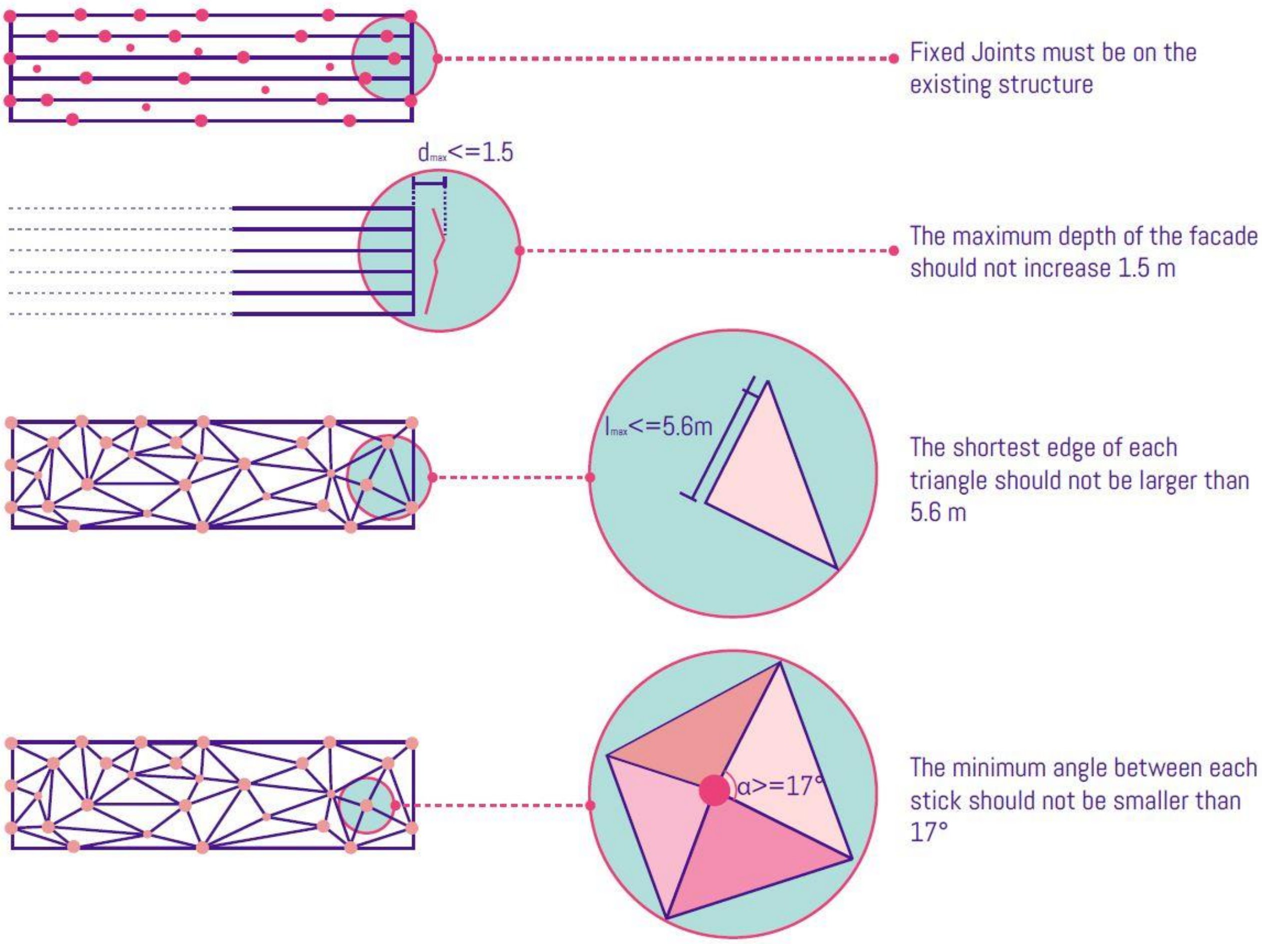


Figure 4 Predefined constraints of the design problem

During these experiments it was observed that the lack of interaction with the heuristic process could negatively influence the search and direct the computer to a wrong direction to find ideal solutions. The only possible access of the designer being the selection at the end of the search process was also establishing an artificial nature in the early design phase where the designer was not in control.

Considering these limitations, it was concluded that to accommodate the playfulness and intuition in the early design phase, the designer's input had to be increased. Accordingly, a new tool is being developed, that can ease the user interaction by making the search process explicit and interactive. Operating within the framework of Rhino Grasshopper, heuristics are used to access large sets of solutions. As a contrast to existing tools, the designer can manipulate the parameters of each variant to generate new solutions. This way the computer can conduct a fast navigation within the solution space, where the designer can explore further solutions by accessing and manipulating the parameters of discovered solutions. By composing a set of different variations, the designer can train an embedded machine learning based system to produce similar solutions regarding their preferences. Unlike the existing optimization tools in Grasshopper where the computer tends to converge towards a mathematical optimum, this training aims to diverge from the mathematical process by embedding the designer's preference, where the computer can discover novel solutions through analyzing features and recurring patterns in the solution set composed by the designer.

Keywords: early design phase, membrane construction, genetic algorithms, machine learning, parametrization, interactive design exploration

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